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DRAINAGE OF MADISON MARSHES

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DRAINAGE OF MADISON MARSHES.

Drainage is a subject of great importance, but one which has been sorely neglected. It has been reserved to the present time to see land draining reduced to a system based on scientific principles. The benefits derived from drainage have been known for many centuries, and rough attempts at draining the soil of superficial water were made. The Romans constructed open ditches to keep their lands dry, and there are grounds for surmising that they used covered drains for the same purpose.

At the present time, land drainage on an exceptionally large scale has generally been associated with Holland and Belgium and to a lesser extent with England. If it were not for drainage, portions of these countries would be buried under 17 feet of water, thus losing some of the most fertile lands in the world.

In England, public attention was directed to the injurious effects of water retained on arable land by the treatise of Captain Blythe in 1652. He recommended straight trenches 3 or 4 feet deep filled with stone or fagots covered with dirt. But little attention was paid to this excellent system until

the latter part of the next century. At this time, Mr. Elkington proposed a plan for draining porous soil underlain by clay. His plan was to tap the confining strata and thus allow the water to flow off to the nearest ditch or stream. At the beginning of the 19th century, a great stimulus was given to drainage of land by the passage of an act, authorizing the advance of public money to promote the improvement of land by works of drainage. About this time, Smith of Deanston discovered those principles of drainage held by Captain Blythe two centuries before, and he proceeded to use them in practice. He insisted on providing every field which needed draining with a system of parallel underground channels parallel to the line of slope at the ground. The distance between drains, was shown to depend upon the retentiveness of the soil. He gave 10' as the minimum, and 40' as the maximum distance. The trenches were 30' deep and filled with 12" of broken stone which would pass through a 3" ring. These drains opened into the main drain, which was carried along the lowest part of the ground, and emptied into some waterway. These principles were speedily adopted and carried into practice, but on account of the labor and cost, incurred in procuring stone,

led to the substitution of horse shoe, and sole tile, and of burned earthenware. These were later replaced by cylindrical tile. The substitution of the cylindrical for the horseshoe and sole tile, has lowered the cost, besides increasing the efficiency and permancy of drainage works. This system introduced by Smith at Deanston, has been virtually adopted by all drainers. A few modifications with respect to the depth and distance between tiles have been made, but no fixed rule can be given for these factors since they depend upon the kind of soil and the rate of rainfall.

METHODS OF DRAINING.

The open ditch is the one most used but in many cases without effect. A ditch to be successful, should be of such a depth that the water in it is lower than that in the surrounding marsh, should have a sufficient fall, not less than 3' or 4' per mile, and should have an outlet. Many persons put in ditches without regard for these essential qualities, thinking that such a method will thoroughly drain the land, and when the ditches are a failure, complain that this is a poor method.

Ditches, if not properly constructed, will do more harm than good. They should be used only where a cheap method is wanted, and when properly constructed and maintained are very effective.

Ditches should not be used in tilled soil on account of the waste of land, and because they are liable to become clogged up, and their effectiveness destroyed. They are very successful for draining lands planted with trees, but unfortunately furnish a place for the growth of weeds which generally are left to go to seed. Ditches in the suburbs of cities are used as receptacles for all kinds of rubbish, and become unsightly, Open ditches are quite widely used as outlets for tile drains. Through the abuse of ditches farmers become so prejudiced against drainage that it is nearly impossible to convince them that drainage of any kind whatever is a paying investment. Where a cheap method is wanted, the open ditch should be used, as it is preferable to stagnant water.

COVERED STONE DRAINS.

Covered stone drains are preferable to open ditches as no ground water is wasted. They require a greater

width than tile drains and are more costly, especially if broken stone is difficult to obtain. There are two important methods for constructing stone drains. The first method is to place a layer of broken stone 8"-12" deep deep in the bottom of the trench, sod is placed on top and the trench filled in. This form is liable to become clogged by the entrance of the soil. The second method is by constructing open drains of flat stones at the bottom of the trenches, but these stones may cave in and stop the action of the drains.

TILE DRAINS.

These are the most permanent form of drains, and are widely used at the present time. The first form used was the horseshoe tile resting on flat stones. These were very difficult to keep in line, and dirt entered them very readily, so they were abandoned.

The single and double sole tiles were next used. These were open to some objection and on account of having to be placed with a certain side down, prevented close joints.

The next type used was the cylindrical tile of the present. They may be laid with or without collars. The

advantages of a collar are - 1st. They prevent the entrance of dirt, 2nd. They tend to keep the pipes in line. but increase the cost considerably.

REQUIREMENTS FOR GOOD TILE DRAINS.

1st. They should have an outlet.

2nd. They should have openings at the joints for the admission of water. These should not be too large and tile having joints greater than 1/4 " should be rejected.

3rd. They should be laid on a regular line of descent, so that the current will be uniform. All of the descent from the head to the outlet should be utilized, and the tiles made as straight as possible. The fall should not be less than 2"in. 100'. Waring says that whenever practicable, a fall of 1'in.100' is desirable, one-half of this is sufficient when the work is carefully attended to. The fall should be distributed over the entire length of the drain, and where practicable, no drain should have a decreasing rate of fall as it approaches the outlet. The chief source of failure is in the filling of the tile with sediment, caused by imper-

fect grade and insufficient fall. Roots are a great source of trouble in tile drains. They enter the joints and tend to choke up the passage. Animals build nests which are also very troublesome. Joints near trees should be protected by a collar, or by cement. A grating over the outlet prevents animals from entering. The tile should run up and down the slopes to obtain the greatest fall possible, and should be parallel if the land will admit it, since the more nearly parallel a system is, the cheaper will it be. The tile should be the smallest that will carry off the water after a heavy rain. The size depends upon the grade and the distance between the drains. The smaller the pipe, the less liable is it to become filled up. From practice it has been determined that a 1 1/4" drain will remove all the water which would fall on an acre during a heavy rain in 24 hours; 2 1/4" tile suffices for 8, and 3 1/2" for 2o acres.

DEPTH.

The depth depends upon the use to which the land is to be put. The depth should at least be sufficient to lower the water table below the action of evaporation, and be below the action of frost. The water table be-

tween the drains is curved, so that the depth must be increased as the distance between them increases. The usual depth for agricultural purposes is 4 feet, but this varies with the soil.

DISTANCE BETWEEN DRAINS.

This varies with the character of the soil. In porous soils the drains may be placed farther apart than in retentive soils.

INSPECTION.

The inspection of tile should be thorough, and no oven or burned tile allowed. The bore should be nearly uniform so as to give a uniform flow.

COST.

A comparison of the different methods shows that tile drains are the cheapest, leaving out of consideration open ditches. In England the average cost of drainage per acre by the use of tile was £5 2s 6d., while that of covered stone drains was £8 14s 9d., showing a decided advantage in favor of tile drains.

EFFECT OF DRAINAGE ON THE SOIL.

Soil consistes of particles of disintegrated rocks. The spaces between these particles should be filled with air, while the pores of the particles should contain as much moisture as they can hold. This is the proper condition, but when the soil becomes saturated through neglect of drainage, the canals and pores both become filled with water. This drives the air out of the soil and thus is lost the oxidizing effect of the air in the soil. Drainage remedies these evils. It takes the water from the canals between the particles, and allows air to enter, thus promoting the disintegration of the soil. Undrained soils do not freeze as deep as drained soils. By draining the soil, the frost is allowed to go deeper, promoting the breaking up of the soil. Waring says that all lands in which the spaces between the particles of soil are filled with water within less than 4 feet from the surface, except during and immediately after heavy rains, require drainage, and if the land is to be used for building purposes, the water table should be at least 6 feet below the surface. A drained soil has its spaces filled with air amounting to one-fourth of the whole

bulk, while the pores contain the moisture. Such a soil never bakes, cracks open or destroys plant life. All rains are taken quickly into the earth, where all the important constituents are utilized by the soil. The farmer with a thoroughly drained farm fears no evil from rain or drought. Thus we see that drainage not only adds to the fertility of the land under cultivation, but renders susceptible of cultivation that which otherwise would be useless.

Drainage elevates the temperature of the soil, as it permits the warm rains to be quickly absorbed. The effect of deep drains is to diminish the effect of evaporation, and thus keep the temperature of the soil higher. As soon as the soil becomes saturated evaporation is the only natural way of lowering the water level, and heat disappears by the conversion of heat into vapor. Every gallon of water evaporated takes away a quantity of heat, sufficient to raise 5 1/2 gallons from the freezing to the boiling point. It is not surprising that saturated land within reach of the wind should be called cold as well as wet.

The importance of drainage is well known to every land owner. It gives a longer time for crops to grow

and mature by enabling early planting. Poor crops are due either to the inherent poverty of the land or to the surplus moisture during the season at early growth. Drainage removes the second cause by preventing the chilling of the soil due to evaporation of the water. The roots of grains and grasses on low grounds do not enter the soil as deep as they should,- as soon as they strike the permanent water-level, they spread out.

EFFECT OF DRAINAGE ON HEALTH.

The effect of drainage upon the health is an important one, but not very clearly understood. No unhealthfulness is caused by water in motion, whether flowing on the surface or underground. The danger arises from that portion which remains stagnant either above, or under the surface. By drainage this stagnant water is removed, and the danger from diseases lessened. The results of all inquiries abundantly demonstrates that drainage is an essential element of the healt of a community. More will be said of this subject later.

EFFECT OF SOIL ON DRAINAGE.

Soils may be divided into three classes:- 1st. Free

or pervious soils, 2nd., Retentive or impervious rock, and 3rd., Mixed soils.

FREE SOILS.

Sand, gravel, and peats belong to this class. These are subject to natural though slow drainage, by percolation from a higher to a lower level and also lose their water by the action of vegetation and evaporation. These soils may be drained by deep drains at wide intervals, the number being governed by their depth, and their position by the form of the ground. Free soils are generally wet from position, and require just enough drains to turn stagnation into motion. The usual distance between drains in such a soil is from 40 to 50'. When once drained they possess the same character as those naturally dry, the only difference being in the depth of the water table.

RETENTIVE OR IMPERVIOUS ROCK SOILS.

These consist of clays. Undrained clay soils only lose their water by evaporation. In this class of soils, drains cannot be put in too close, the number being limited only by the cost. The usual distance between the drains in clay is from 20' to 40'. A distance greater

than 40' would not be safe. Drains in these soils do not s up as rapidly as in other soils. Though clays may be rendered permeable to water by underdraining, they still possess a peculiar retentive and expansive power which limits their capacity for absorption, and causes them to restrict the entrance of rains. These soils cannot be aerated too much, as it is only by this method that their retentive nature can be held in subjection. The true theory of drainage is perfect aeration of the soil, both from the surface to the drains, and from one drain to the next. Due to the increased number of drains, the cost of draining clay soils is greater than that of draining free soils.

MIXED SOILS.

These consist of a mixture of the other two, being partly pervious. In their undrained state they retain water and give it off as vapor. The retention of water depends upon the abundant clay in the soils, increasing in proportion as the clay increases. There can be no rules laid down for the drainage of such soils, but frequent drains have been found to be the best. In dealing

with such soils the engineer must use his own judgment, drawing his conclusions from the drainage of similar soils under like conditions. Dempey, a writer on drainage, says that soils containing 10% of argillaceous matter will require the aeration of frequent and uniform under-drainage.

DRAINAGE IN THE UNITED STATES COMPARED WITH THAT IN OTHER COUNTRIES.

Drainage in the United States does not compare very favorably with that of some of the European countries.

DRAINAGE IN HOLLAND. The lands in Holland are to a great extent reclaimed lands. It is said that the Dutch gaze upon their marvelous country, and proudly say:- "God made the country, but we made the land." Were it not for the Engineer, Holland would not be in existence today. Holland is divided into numerous polders. These are areas of agricultural lands of recognized boundaries, divided into small lots surrounded by Dike protection. In Holland the occupied land is several meters below the level of the sea. The soil here must be protected from the waves, grinding of the ice, and the

scouring of rivers. The methos of drainage in Holland is to place a dike around the surface to be drained. The area is then kept dry by pumping. Windmills were used in earlier days, and are even now to some extent, but steam is generally used.

The drainage of Harlem lake was a great undertaking, the area being 70 square miles. The ring dike is 37 miles long and extends around the entire lake. The amount of water lifted by the pumps to drain the lake was 9,000,000,000 tons. After drainage, the lake was crossed by numerous canals and ditches to convey the water to the ditches. The total cost was about $3,242,000, and the cost per acre about $10.

In Italy, Belgium, Austria and England, extensive drainage operations have been carried out. In England large quantities of water have been raised to a great height, and the lands successfully drained thereby.

DRAINAGE IN THE UNITED STATES. The principle drainage districts in the United States are Illinois and Ohio. Illinois leads in the drainage of agricultural land in this country, and excepting Holland, in the world. This statement is especially true with respect to tile under-

draining and ditching. The largest drainage scheme in Illinois is a ditch between Pekin and Havana. The main system is about 14 miles long, 10' deep, 30 feet wide at the bottom, increasing to 60' at the top. The total length of ditches in this system is 70 miles long. Drainage operations in Illinois have been very successful, and new areas are constantly being drained.

There are areas in the United States which could be very profitably drained by the system used in Holland, particularly the areas in New Orleans and other southern states.

The above cited examples go to prove that drainage when properly carried out is a decided success.

It is strange that such enterprising people as the Americans are, should allow themselves to be so far behind smaller countries in the matter of drainage. A striking example of this neglect may be found in the city at Madison, which is situated between two marshes, one between the Capitol and the Chicago, Milwaukee and St. Paul Ry., and the otherbetween the Capitol and the Catfish river. During the past fifteen years these marshes have been a continual source of anxiety to the residents.

Various schemes have been suggested and others tried for lowering the level of the water,- among these are ditching, lowering the water at Third and Fourth lake, filling in, etc.. Mr. Waring and Professor Conover have both suggested plans for lowering the water level, which will be referred to later. In spite of the fact that this question has been agitated by the citizens for a long time, the marshes are still in existence, promoting disease daily which might otherwise be prevented. It seems a pity that a city of 15,000 inhabitants, and one which has such a beautiful location as has Madison should allow such a state of affairs. The marshes are one of Madison's greatest drawbacks. The cost of removing the marshes would be trifling compared with, the improved condition of the city from a healthful standpoint, besides the increased value of the land.

The marshes in their present condition are practically valueless. The marsh lying to the northeast is always under water in places, and during the spring, a small lake of stagnant water is formed. These marshes have for many years been used for public dumping grounds. Manure, decayed vegetables, etc., are deposited here day

after day, and must of necessity furnish conditions for the promotion of diseases, not only to the persons living upon the marsh and near it, but to the entire city.

They are a breeding place for malaria, typhoid fever, diphtheria, and other diseases of a similar nature. It is true that during the past two years attempts have been made to prevent the marsh from being used for public dumping grounds, but they have not been very successful. We cannot expect the people to be in a healthy condition when such things are being carried on.

The people living near the marsh belong to the poorer class, and have purchased these lots because they are cheap. In order to build their houses, it has been necessary to fill in to some extent. Barely enough material has been put in to cover the surface water, and this is used for a foundation. The cellars, if there are any, in the higher lots, will be filled with water during the spring and at all times during the year, the houses will be in a damp condition.

The class of diseases most frequently noted in connection with damp cellars are, rheumatism, diphtheria, bronchitis and pneumonia. Damp cellars cause a lessen-

ing power of resistance to all diseases. A large number of preventable diseases are caused by damp cellars. The words of Dr. Kedsie in this connection apply very well to the state of affairs in the vicinity of Madison:- "Here lie in ambush, diphtheria and membraneous croup, the destroyer of childhood, and typhoid fever that strikes at all ages. Here lurk the seeds of consumption to bring forth the the slow but sure harvest of lamentation and woe." For a proof of the statement it is only necessary to notice the number of cases of sickness in Madison in one year.

The air above the marshes and for a considerable distance around is damp from excessive evaporation; this is a further cause for such diseases as consumption.

Many people living upon or near the marsh receive their water supply from sources very near the marsh. These wells cannot furnish a good water supply when stagnant water is so close at hand. The refuse dumpded upon the marsh decays, filters through the soil, and enters the well, making conditions favorable for bringing forth epedemics, and increasing those already started.

Madison has a well-earned reputation for being an unhealthy city. Scarlet fever, typhoid fever, diphther-

ia and measles are the most important diseases.

A comparison was made between the number of cases of diphtheria, measles and typhoid fever, which occurred in several towns in New York and Michigan with those occuring in Madison. It was found that the death rate in Madison was very much greater than in either one of these states. The health reports in Madison are not very complete, so it was rather hard to make a comparison. Even in cities having 5,000 more inhabitants than Madison the number of cases of diphtheria was very much less than in Madison. The prevalence of diphtheria in Madison was evident from these comparisons. Michigan and New York were chosen because the other states did not give the desired data. In all of these comparisons, Madison led the list.

THE EFFECT OF DRAINAGE upon the marshes may be divided into two parts:- 1st, The effect upon the health, and 2nd, The effect upon the value of the property.

EFFECT UPON THE HEALTH. The stagnant water would be removed and the land left in a dry condition. The drains would be placed at such a depth that cellars could be constructed without any fear of dampness, thus lessening the occurrence of such diseases as diphtheria, rheu-

matism, etc.. The dumping of rubbish in the vicinity would be prevented, and the city would be improved wonderfully by such an undertaking.

EFFECT ON VALUE OF LAND. The land would be increased in value. Lots worth from $75 to $100 would then be worth from $400 to $800. Not only would the marsh property increase in value, but also that in the vicinity of the the marsh.

During the first year it would probably be hard to overcome the prejudice which always exists whenever such an undertaking is proposed. It would take but a short time to convince the skeptical ones that their fears are entirely groundless. The taxation upon the property would be increased to such an extent that the city could afford to pay for the necessary pumping.

Many schemes have been proposed for lowering the water level in the marshes. Filling has been done to a great extent. The ordinary method of filling is to use rubbish, dirt, etc.. Barely enough to cover the surface water. Stone to a depth of two or three feet with a covering of dirt has been used with success. This method is very good for the building of factories, etc., which do not need cellars, but should not be used as a

foundation for dwelling houses, and then too it is very expensive. A gentleman who has filled several lots in this way considers them worth $2,000 apiece, but of course this is rather high.

It has been suggested by some to fill the marsh with material brought in by the railroads. Mr.Waring in his report on the marshes, says that this would cost about $200 per lot, besides the heavy expense to the city of filling in the streets to the necessary level.

DITCHING has been tried to some extent but with very poor results. A number of ditches have been dug but have not been maintained, and even if they had been, would propbably not have done very much good, since there is no outlet after the water reaches them.

It is thought by some that the water in the marshes is due to percolation of the water from Lake Mendota through the soil. A scheme for lowering the lakes is being very strongly agitated in the papers at the present time. It is proposed to take out the dam between Mendota and the Catfish. Lake Mendota is about 4' higher than the Catfish, and since there is a fall between Mendota and Monona, this would lower lake Mendota about 4 ',

thereby preventing the percolation of the water through the soil.

The greater part of the water in the marshed is not due to percolation, but to the rains which collect at the low point, the marsh being surrounded on three sides by steep hills. It is barely possible that lowering the level of Fourth lake will lower the level of the water in the marsh. The simple lowering of Mendota will not leave the marsh in dry condition. It will probably be quite dry, during a dry spell, but will surely be under water after a heavy rain. Even after having removed the dam it will be necessary to put in intercepting sewers to take charge of the water coming from the side hills. These will have to be at such a low level that pumping will be necessary. A great deal of filling too will probably have to be done in order to build cellars. The surface of the water will be about 4' from the surface of the ground, which is not deep enough for cellars. The lowering of the lake will leave beaches along the shores, of 60 or 100 feet in width. The health of the city would probably not be effected by it, but Mendota would no longer be the beautiful lake it is at present.

The beaches formed would be public highways, unless the owners fenced them in, or filled in. A shore made up of filled in lots and beaches would certainly be anything but pretty. The boat houses along the shores, some of which are very costly structures, such as the University boat house, the one near Vilas' , and several others, would have to be moved, or canals constructed leading to them.

A bill was passed in the legislature of 1889 which proposed to take out the dam at Stoughton, thereby lowering the level of Third lake, and draining the marsh lands along the Catfish. This was strongly opposed by many farmers, who knew that most of their land would be left too wet to cultivate, and too dry for raising hay successfully, and the scheme would be very damaging. About $21,000 was spent in surveying, and nothing was done; finally, the scheme was dropped.

The scheme ~~was~~ now proposed of lowering Mendota will probably fare the same way as the one just mentioned. The people living along the lakes will object seriously to having them spoiled by lowering the lake. A large number of surveys will have to be made, after which this

scheme as the other one, will probably be dropped.

The only reliable plan for lowering the level of the water in the marsh seems to be a thorough system of drainage. The surveys would not be very elaborate and when the drains are once put in all the water will be provided for. No filling will need to be done and the cost will not be very great.

THE PROPOSED SYSTEM.

It is proposed to put in a system of drainage to provide for the largest rains which can reasonably be expected to occur. The sewers and drains will be placed at such a depth that no fear from dampness need be entertained.

The system may be divided into two parts:- 1st, Drainage of the upper level, and 2nd, Drainage of the lower level. A large part of the water in the marsh comes from the hills which surround it on three sides. This part of the area will be provided for by means of intercepting sewers, which will be placed as low down as possible and still allow a gravity flow. Some of the hills, from which water flows into the marsh, can not be provided for by intercepting sewers and will have to be

included in the low level system.

LOW LEVEL. The low level system is about 300 acres extending from Blount St. east to the Catfish, and from Johnson St. south to Williamson St., with the exception of two small areas which are drained by intercepting sewers. The maximum elevation of the surface is but 5' above the city datum, while its average elevation is less than 2' above, and some portions are below the datum. Thus making thorough drainage by a gravity system impossible. Resource must therefore be had to pumping. The water will be collected in a reservoir at some low point. The surface water will be provided for by means of sub mains on the streets at right angles to Washington Ave., along which extends a main sewer emptying into the reservoir. These submains are connected with the main sewer at each street intersection.

The soil in the marsh is composed of clay, sand and loam. The top foot is a black loam, below which is from 3 to 4 feet of clay, underlain by a sandy clay. This soil will need frequent drains. These drains will intersect the sub mains at intervals of about 40 or 50 feet. Man holes or catch basins will be placed on each

street intersection, on the main sewer, on the sub mains; man holes will be placed every 400 or 500 feet; mains and catch basins at each street intersection.

DESIGN OF DRAINS. In the design of drains the maximum rate of rainfall is a most important element in determining the size of the sewer. The total precipitation during a storm is of little value but the intensity per hour during the period of time necessary for the water from the most distant parts to reach the outlets, is the chief consideration. The records of rain-falls which will furnish this information are few, and can only be obtained by the use of automatic gauges. The ordinary records of rain-fall give only the total precipitation, and possibly the duration of the storm, but as the storm may extend over several hours, with a variable intensity, the total precipitation will bear no relation to the maximum rain-fall. This maximum rain-fall is not subject to so great a variation in different localities as is the total yearly fall. Localities with rainfalls varying between wide limits present but little difference in the maximum amount which falls in a fixed time, say twenty minutes. Professor Talbot of the University of

Illinois, has collected all the records of maximum rain-falls available, and has platted curves of maximum rain-falls for each available district. The ordinates being the rate per hour, and the abscissas, duration in minutes. The equation of the curve of ordinary maximum was found to be $y = \frac{105}{x+15}$. The curves platted from this equation show a uniformity of maximum precipitation in different parts of the United States. This equation does not provide for excessive rain-falls, since they occur only at long intervals, and are of short duration. The construction of the sewers to meet these excessive storms would be attended with great expense, while the damage done by overflow during these excessive rains would be less than the interest on the first cost of constructing the sewer to provide for such emergencies.

The sewers for both the intercepting and the low level system were designed by the use of this equation. The sizes thus obtained, ckecked very closely with those as found by the use of McMath's diagrams, used in the design of sewers at St. Louis. The proportion of the rain-fall reaching the sewer depends upon the character and condition of the surface to be drained. That por-

tion of a city which is well built up, gives a high percentage of storm water, while grassy areas and flat, open districts will give but a small percentage.

The sewers were designed on the supposition that all streets were paved, and the percentage of water reaching the sewer was taken, as being approximately equal to the percentage of paved area, about 30%. The final formula for finding the discharge in cubic feet per acre was:-

$Q = \dfrac{63\,a\,o\,f}{\frac{l}{v} + b + 900}$ where Q = discharge in cubic feet.

f = proportaion of rain-fall reaching the sewers, .3 in. in this case; l = length of sewer.

v = velocity in ft. per second of water in sewer.

b = time in seconds necessary for the water to reach sewer inlet.

This formula assumes that the discharge in cubic feet per second per acre is equal to the number of inches of rain per hour. This is approximately true as the difference is less than 1%. Multiplying the discharge in cubic feet per acre by the number of acres, we get the total discharge, and knowing the discharges and grade of the sewers, the size was readily determined from tables of capacities. In designing the sewers the size was found at each street intersection.

RESERVOIR AND PUMPING HOUSE.

These will be built in block 215 at the intersection of Washington Avenue and Dickinson Streets. The cost of land here will be less than in any other place.

The size of the reservoir will be such that the total cost of reservoir and pump will be a minimum. To determine this Resource must be had to Calculus. In the design of the sewers, Talbot's formula was made use of. $t = \frac{105}{t+15}$. This gives the number of inches of rainfall per hour for minutes. Since the number of cubic feet per second is nearly equal to the number of inches of rainfall, we have the discharge per second from 300 acres, of which 30% is impervious.

$$Q = \frac{105}{t+15} \times .30 \times 300$$

or the discharge per minute $= \frac{105}{t \times 15} \times .3 \times 300 \times 60$

$= \frac{K}{t+15}$ where K = 105 x .3 x 300 x 60 - 567.000

Let x = capacity of reservoir in cubic feet.

Let y = capacity of pumps in cubic feet per minute.

Let t = duration of rain-fall in minutes.

$$x + yt = t\,\frac{K}{t+15}$$

$$y = \frac{Kl}{t+15} - \frac{x}{t}$$

Let a equal cost of reservoir per cubic feet in cents,

Let b equal cost of pumps per cubic feet per minute in cents,

$$ax + by = c = \text{cost}$$

$$ax + \frac{bk}{t+15} - \frac{bx}{t} = c$$

$$\frac{dc}{dt} = -\frac{bk}{(t+15)^2} = \frac{bx}{t^2} \quad \text{putting} \quad \frac{dc}{dt} = 0$$

$$\frac{k}{(t+15)^2} = \frac{x}{t^2} \quad \text{or} \quad t\sqrt{k} = (t+15)\sqrt{x}$$

$$t = \frac{15\sqrt{x}}{\sqrt{k}-\sqrt{x}}$$

The + value of the square root being taken as t cannot be negative. Substituting this value of t in the equation of the cost, we have

$$ax + \frac{bk}{\frac{15\sqrt{x}}{\sqrt{k}-\sqrt{x}}} - \frac{bx}{\frac{15\sqrt{x}}{\sqrt{k}-\sqrt{x}}} = c$$

$$ax + \frac{bk(\sqrt{k}-\sqrt{x})}{15\sqrt{k}} - \frac{bx(\sqrt{k}-\sqrt{x})}{15\sqrt{x}} = c$$

or

$$ax + \frac{bk}{15} \quad \frac{b\sqrt{k}\sqrt{x}}{15} - \frac{b\sqrt{x}\sqrt{k}}{15} + \frac{bx}{15} = c.$$

$$\frac{dc}{dx} = a - \frac{b\sqrt{k}}{15\sqrt{x}} + \frac{b}{15}$$

$$15a\sqrt{x} - b\sqrt{k} + b\sqrt{x} = 0$$

$$\sqrt{x}\,(15a + b) = b\sqrt{k}$$

$$x = \frac{kb^2}{(15a+b)^2}$$

The value of x is the capacity of the reservoir which will make the total cost a minimum, as $\frac{d^2c}{dx^2}$ is positive when the value of x is substituted in the $\frac{d^2c}{dx^2}$

The cost of reservoir per cubic foot capacity was taken as the mean of the cost of six large reservoirs in different parts of the country, or 12 cents per cubic foot. In determining the size of the reservoir it was necessary to know the cost per cubic foot per minute of pumps. A compound direct acting pump engine was decided upon for reasons which will be referred to later. In finding the mean cost per cubic feet per minute of the pump, the mean of six compound engines in actual use was taken. This mean cost was found to be $34 per cubic foot per minute.

Substituting the values of a and b in the formula for the capacity of reservoir for a minimum cost and the

value of k already noted, we have:-

$$x = \frac{56700\,(3400)^2}{(15 \times 12 = 3400)^2} = 511400 \text{ cu. ft.}$$

$$b = \frac{15\,\sqrt{511400}}{\sqrt{56700}\,\sqrt{511400}} = 286^{m.} - 4^{h.}\ 46 \text{ min.}$$

Substitute the values for x and b in the equation for capacity of pumps, and we have $y = \frac{567000}{301} - \frac{511400}{286}$ = 95.6 cu. ft. per minute.

This is the arrangement which will give the minimum total cost. The large difference between the value for the capacities of the reservoir and that of the pump is d due to the large difference in the cost of a cubic foot capacity of the reservoir, and the corresponding cost of the pumps. Such a large reservoir would be impractica-ble as it would take nearly four days for such a pump to empty it, and during the four days, another heavy rain might occur and flood the reservoir. Besides this, the water flowing in is apt to contain street clearings and other material which it allowed to remain would settle and cause a nuisance. The pump must therefore be at such a capacity that one day's pumping will empty it and

leave it in a condition to receive another rain. In order to prevent the filthy water from becoming a nuisance, the pumps should be large enough to pump out the entire amount in less than 24 hours from the beginning of the rain.

The total amount collectable from the maximum rain fall = $\frac{t\,K}{t+15}$ = 538700 cu. ft.

Capacity of pump = $\frac{538700}{60 \times 24}$ = 375.4 cu.ft. per minute. This is the capacity of the pump required to discharge the total amount in 24 hours and thus thus be ready for the next rain.

Capacity of reservoir = 538700 - 286 x 375.4 = 431,300 cu. ft.

If the total amount must be provided for in 24 hours, the capacity of the pump would need to be 4,040,000 gallons per day. A 5,000,000 gallon pump will be used, ~~th~~ thus allowing a slight factor of safety.

The style of pump chosen is a High Duty Horizontal Compound pumping engine of the Gaskell type with a capacity, as before stated, of 5,000,000 gallons per day.

A horizontal type was chosen in preference to a vertical one for the following reasons:-

The horizontal position seems to be the natural one for permanent service. They require a less expensive foundation, and cost less to build, transport, and erect, than a vertical engine.

It is more easily handled because all of its parts can be manipulated from the floor, and as its pumps are above the floor they can be more readily repacked and more closely watched, than if they are below the floor in a damp, dark place, as is usual with pumps of a vertical engine. The only objection urged against them is that the friction and wear of the horizontal piston and plun--ger comes all on the bottom of the cylinder, but the greater facility with which it can be repacked more than offsets this objection.

A compound engine was chosen in preference to a single engine, because a greater amount of work is obtained from a given quantity of steam, by exhausting from the high pressure to the low pressure cylinder, instead of exhausting into the air. In this way a higher duty per 100 of coal is obtained, which causes a great saving of coal. The first cost of a high duty pumping engine is greater than that of a low duty, but the gain in economy at first will more than offset this. The pumping

engine chosen is of the double type; each half can be worked independently of the other half.

The first cost of a centrifugal pump and engine would have been cheaper, but the pump would have to be placed down in the reservoir, or the suction would be too far an economical use of the the pump. If placed in the reservoir, the pump would be hard to get at in case of an accident during high water. The duty of this pump is low, and the fans and casings wear out rapidly by the action of the grit and water. This would require a new pump, which in the case of a plunger pump, packing only is necessary. It was at first thought necessary to have a relay pump, but as the proposed pumping engine is double and each high pressure cylinder obtains steam from the boiler independently of the other, no relay pump will be necessary.

The design and location of the reservoir and pumping house are shown on PLATE II.

The reservoir is 120 x 240 ft. inside dimensions, and is 15 ft. high to the springing line of jack arches. The roof is supported by 12 rows of piers 16" square and 12 ft. center to center. Connecting these longitudinally are 24" I Beams, from which the arches spring. The

outside wall is 4 1/2' wide at bottom and 2' wide at the springing line, with a batter of 1 on 15 inside and 1 on 10 on the outside. The reservoir is constructed of rubble masonry laid in cement, and on the outside of the wall a 1/2" layer of neat Portland cement is to be used as a plaster coat. The floor of the reservoir is a 6" layer of concrete. The piers, arches and spandrel walls are to be of brick laid in cement. For the purpose of clearing and ventilation two manholes are placed at each end, and if farther ventilation is necessary the reservoir can be connected with the chimney of the of the boiler house. The boiler house will contain 4, 100 H.P. horizontal boilers. The H.P. required to lift 5,000,000 gallons 30 ft. is about 270, and if 4, 100 H.P. boilers be used; the plant need not stop if one of the boilers break down.

A spur track could be run from the Chicago and Northwestern railroad to the coal shed, thus saving the expense of hauling coal from the city.

COST OF PROPOSED SYSTEM.

Main Sewer..................................	$29,489
Low Level Sewers...........................	25.187
Intercepting Sewers........................	19,951
Tile Drains..................................	20,838
Manholes, 56@ $22,50	1,485
Catch basins, 79@$16.	1,264
COST OF RESERVOIR.	
Exc 32,000 eu. yds.@ 60cts...............	19,200
Rubble mas. 1400 cu. yds.@ $6...........	8,400
Cement, 540 cu.yds.@ $5..................	2,700
623 cu.yds. of brick masonry in cement..	1,062.30
1/2 " cement plaster, 4414 sq.yds.@ 40c.	1,770
2160' at 24'I Beams 80"per ft. 2 for	3,456
Cost of sand................................	1,500
78 tons of 16"cast iron force main @ $22	1,716
Engine House and Boiler Room............	7,000
Pump and Boilers...........................	12,800
Total	$157,818.30
Engineer's fees and contingencies.......	15,781
Total	$173,600.13

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The cost of the proposed system is $173,600.13. This will be compared with the cost of filling which is the only other scheme practicable. The cost of filling as proposed by Mr. Waring would be $200 per lot, without reckoning the cost of grading the streets afterwards. Allowing 300 acres as the area drained, the cost per lot of the proposed system would be $145, thus showing a balance of more than $55 per lot in favor of the proposed system. The system could very readily be constructed, and the sooner Madison adopts this system, or a similar one, the better will it be for her citizens.

WEST MADISON MARSH.

Regarding the drainage of this marsh, a paragraph will be quoted from Professor Conover in his report on the Madison marshes.

"The marsh lying between the center of the city and the St. Paul railway, has a general elevation of between 4 and five feet above the city datum, or ordinary low water of lake Monona and is capable of being easily and completely drained." But this marsh is not as important as the one on the east side.

If the system proposed, will set the people of Mad-

ison to thinking along this line, to the extent of adopting some system of drainage for these marshes, we will feel that our time and trouble has been well repaid.

Approved
Professor F. E. Turneaure
Bridge and Hydraulic Engineering
per N.O.W.